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Remote Sensing Characterization of Selected Waste Sites at the Los Alamos National Laboratory

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ABSTRACT
The paper presents some examples of the use of remote sensing products for characterization of hazardous waste sites. The sites are located at the Los Alamos National Laboratory (LANL) where materials associated with past weapons testing are buried. Problems of interest include the detection and delineation of buried trenches containing contaminants, seepage from capped areas and old septic drain fields, and delineation of strata for soil sampling. Imagery products shown in this paper were derived from airborne multispectral Daedalus data, SPOT satellite imagery, aerial photography, digital map information and engineering drawings of sites. Site managers at LANL suggested the environmental areas in need of assistance and participated in the interpretation of imagery. Overlays of suspected trench locations on thermal images showed correlation between image signatures and trenches. Another thermal image showed warm anomalies suspected to be areas of water seepage through an asphalt cap. Some new cold spots were discovered that could be buried objects. Merging of hydrographic and soil contaminant data with imagery provided aids for soil sampling. Overlays of engineering drawings on recent and historical photos showed errors in trench location and extent. Multispectral images showed correlation between image signatures and engineering drawings of drain fields.

INTRODUCTION
A legacy of the cold war with its emphasis on weapons production has led to environmental problems at the Department of Energy (DOE) sites where nuclear weapons and materials were produced. The present problem is widespread, occurring at sites in 34 states, involving a wide variety of wastes including radionuclides, and hazardous organic and inorganic chemicals. Current efforts are underway to detect, map, characterize, and clean up subsurface contaminants including leakage from landfills and other contaminated plumes, buried objects such as pipes, drums and tanks, old buildings, covered trenches and pits.

Unfortunately, areas of waste disposal at DOE sites are not all documented and located. There are a number of reasons for this situation: records have been lost or destroyed, the locations were never documented, and memories have been lost. The search of large areas at these sites for buried waste and buried waste containers is a difficult and expensive problem when using conventional, ground-based methods. Typical conventional methods involve the drilling of wells/boreholes (point sampling) and interpolation between holes is required to obtain the needed areal information.

Drilling for buried waste is expensive, potentially hazardous, and time-consuming, yet accurate interpolation can require a large number of holes per-unit-area. A similar problem is encountered in gaining current information about the boundaries of toxic waste plumes in the ground, transport pathways, and the composition and concentration of toxic materials.

With costly drilling operations the reduction in the number of holes is of great concern. And just as importantly, safety must be a principal consideration when drilling to explore for unknown buried waste. An alternative to conventional ground-based methods is the use of remote sensing methods to reduce the ground area to be considered and amount of actual drilling needed.

LANL is the test facility for this study using remotely sensed data from aircraft and satellite. Many of the chosen sites had archival data available for analysis which included aerial photography, multispectral and infrared imagery. Those data have been collected by commercial and Government sensors, and span an appreciable time interval.

Several known and suspected sites at LANL were chosen as important areas in need of help from remote sensing. Existing imagery from each area was reviewed and site managers collaborated on the concept for solutions. The images shown in the paper are from airborne multispectral Daedalus collections made by DOE's Remote Sensing Laboratory (RSL), coincident natural color aerial photography, SPOT satellite imagery, and historical photographs. Other information includes digital map data and engineering drawings of burial sites.

The Environmental Research Institute of Michigan (ERIM) was contracted by DOE's Morgantown Energy Technology Center (METC) to collect the data, choose sites of focus, and perform special processing. The results have been presented to LANL on-site managers for determining the site-specific applications. The project is documented in a METC final report (David and Ginsberg, 1995).

SITE SELECTION

Between 3 and 10 sites were sought to demonstrate the use of remote sensing for DOE waste sites. A technical workshop was held in Los Alamos to invite LANL site managers to suggest and review potential sites. to be a final candidate, a site had to satisfy 5 criteria:

1.) The LANL Environmental Restoration Program felt that there was a problem to be solved at the site.
2.) Some problem at the site was amenable to a remote sensing solution, that is, image exploitation was scientifically possible.
3.) A site manager would take an interest in the project, that is, would take the time and had the knowledge to help find a solution.
4.) Good ground truth was available so that the demonstration products would be credible.
5.) Imagery at the right times, wavelength, resolution, etc., was available.

Six sites were selected and they are shown on Figure 1, a 1991 panchromatic SPOT image of LANL. The LANL boundary and general locations of each site are designated on the figure. Sites were named after the site manager that expressed an interest:

Becker Site: Displaying sampling areas by hydrologic category and contaminant concentration.
Hoard Site: Locating pits and comparing to engineering drawings.
Koch Site: Evaluating faults and fractures beneath waste disposal areas.
Mason Site: Assessing thermal hot spots in an asphalt cap; locating other contaminated trenches.
Mynard Site: Determining location and extent of seepage from septic drain fields.
Rofer Site: Detecting and delineating suspected trench locations.

ANALYSIS METHODS

Most of the image processing for this paper concentrated on the Daedalus multispectral imagery. Once some basic softcopy multispectral images were constructed, a visual procedure was started, analyzing these images along with SPOT, Russian KFA-100, and Landsat satellite images, historical and concurrent aerial photographs, site maps, and other ground truth. The phenomenology of the signature of the particular waste site problem guided the special processing of an image. Signatures of known trenches and objects were compared to those of suspected trenches and objects. Often no additional image processing or image analysis was needed on any one image, but information from more than one image or map needed to be fused to aid the site managers in assessing a problem. This was especially useful at waste sites where there were conflicting information sources concerning buried waste locations.

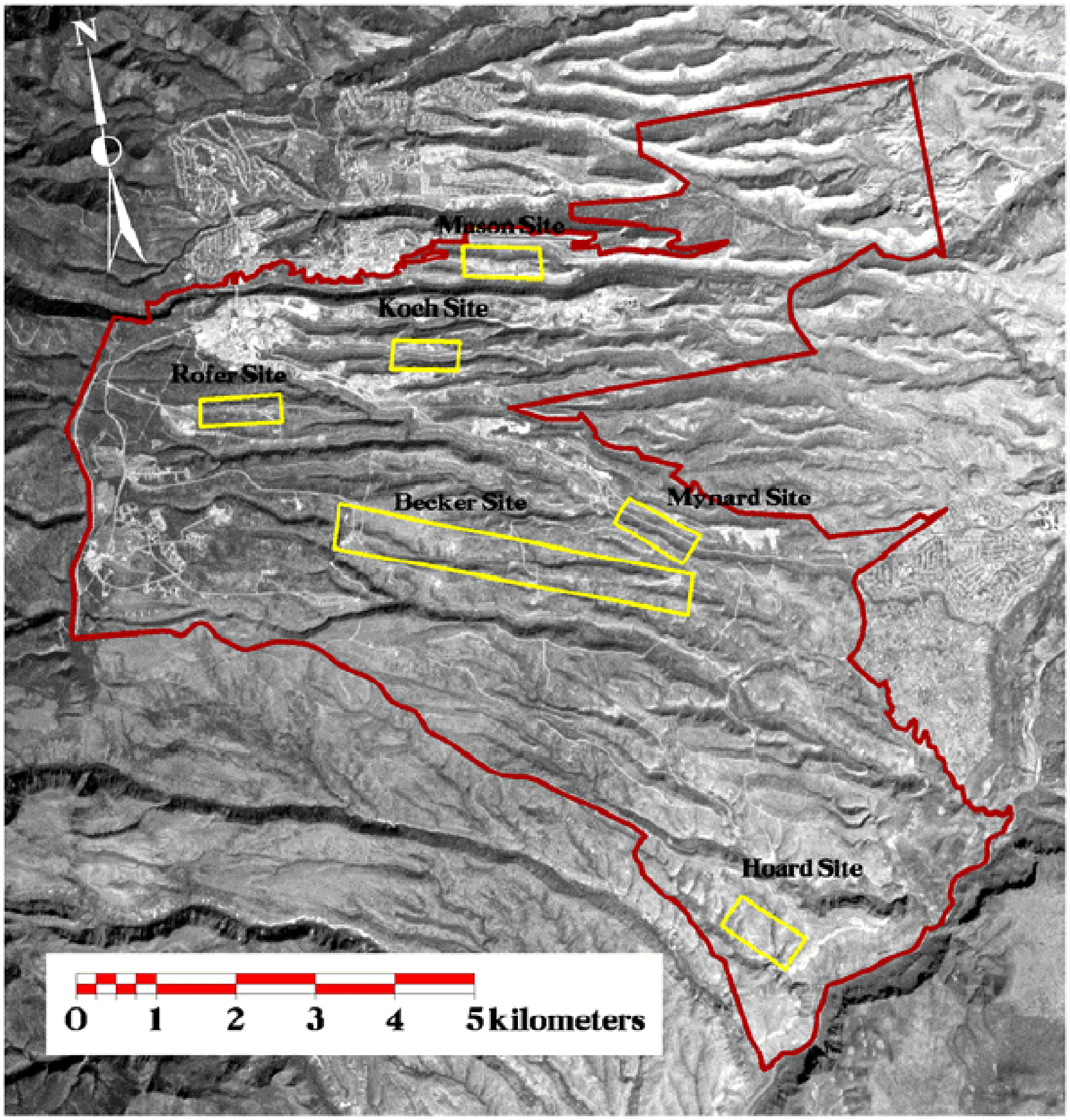


Figure 1: Sites Selected for Evaluation at the Los Alamos National Laboratory

Data Fusion to Aid Users: To provide a physiographic representation to the site analysts, layers of information were georeferenced and added. A typical application is to use multiple sources to aid in confirming or denying positions of buried objects. Imagery available in digital form was directly entered as a layer. Maps, diagrams, drawings, or photographs not available in digital form were digitized or scanned, depending on the material. Information from georeferenced data bases were added as other layers. Often the layers of information were overlaid on a background image for context and for integration of the geographical features. Commercially available packages were used, the choice depending on the particular workstation being used and the preference of the particular analyst.

Daedalus Multispectral Imagery: DOE has made flights over the waste site areas with a helicopter operating the Daedalus AADS 1268 Multispectral Scanner and a 70mm aerial framing camera. These data are collected, analyzed, and archived by RSL. The RSL data base permitted retrieval of flight logs and imagery of the flight lines covering the pre-selected sites.

A set of flight lines were selected from the collection on 24 June 1994. These included both daytime and pre-dawn collections. The daytime imagery contained eight bands. The nighttime imagery contained only thermal bands (high and low gain channels). Flight lines were flown at an altitude of 1000 to 1500 feet AGL yielding a ground resolution of 2.5 to 3.75 feet and at 5000 to 5500 feet AGL with resolution of 12.5 to 13.75 feet.

The Daedalus scanner AADS 1268 is capable of collecting data in up to 12 spectral bands. The following bands (corresponding to Landsat TM bands) were archived and used for this project:

Daytime Multi-spectral Imagery:

Band 1	0.45-0.52 µm	TM-1
Band 2	0.52-0.60 µm	TM-2
Band 3	0.63-0.69 µm	TM-3
Band 4	0.76-0.90 µm	TM-4
Band 5	1.55-1.85 µm	TM-5
Band 6	2.08-2.35 µm	TM-7
Band 7	8.5-12.5 µm (low gain 0.5)	TM-6
Band 8	8.5-12.5 µm (high gain 1.0)	TM-6

Predawn Thermal Imagery (long wave thermal band only):

Band 1	8.5-12.5 µm (low gain 1.0)	TM-6
Band 2	8.5-12.5 µm (high gain 2.0)	TM-6

Natural color aerial photography was also collected coincident with all flight lines. This provided very high resolution (estimated at 8-12 inches) with sufficient overlap to permit stereo analysis.

The Daedalus imagery was retrieved from 8mm exabyte tape using both ERIM's and commercial software. The sites of interest were identified on the flight lines in softcopy, and smaller images of the individual sites were taken from the flight lines. This was done to ease the analysis by reducing the amount of data.

Preliminary Visual Image Analysis for Detection Problems: Imagery was examined for signatures indicating the locations of trenches, other buried objects, and contamination problems. These features were identified via site maps provided by Los Alamos. It is expected that detectability is driven by a variety of phenomena, including soil moisture, soil compaction, soil type, and vegetation type and vigor. Therefore, the first analysis step was a preliminary review of all data, with emphasis on daytime and nighttime thermal and reflective multispectral data. The preliminary analysis was visual, using single images, multiple images in a side-by-side presentation, and multi-band or multi-image composites where appropriate. Data transformations such as Tasselled Cap (Kauth and Thomas, 1976) and Principle Components (Jensen, 1986 or Colwell and others, 1983) were applied to the multispectral data, and day/night thermal data was evaluated for thermal inertia effects. Histograms and scatterplots were created and analyzed. Following the preliminary analysis, a more detailed analysis was done to better understand the conditions under which the signatures can be detected and to enhance detectability where possible.

Generally, there were three classes of targets:
1.) Locating buried objects or trenches,
2.) Detecting seepage from buried objects, pits, or drain fields and
3.) Detecting faults and fractures.

These targets were linked to a set of observable features.

Buried objects or trenches usually involve a significant disturbance of the soil which can have a long lasting and often visible effect in the surface. The process of digging up and replacing a large volume of soil creates differences in soil compaction and composition of the disturbed area in contrast to the surrounding undisturbed soil. These differences may result in different drainage over the effected area. Drainage differences result in soil moisture differences which, in turn, may result in vegetation differences (either vigor or type) and thermal differences due to differential evaporative cooling of the surface. In addition, trenches may cause subtle features on the surface either as subsidence due to settling or decay of the buried material, or it may leave a mound where excess material is piled on top of the trench.

Seepage from buried objects, pits, or drain fields results in soil moisture and nutrient differences which, in turn, may result in vegetation differences (either vigor or type), and thermal differences due to differential evaporative cooling of the surface. When the area has an asphalt cap, thermal differences from cracked areas indicate a possible problem.

Faults and fractures may also result in soil type and soil moisture differences which may be directly or indirectly observed by assessing vegetative differences. Changes in surface temperature due to differences in soil moisture can often be observed in thermal imagery. If the surface is covered by vegetation, the age, type, and relative vigor can sometimes indicate the location of faults and fractures.

Burial Site Analysis: Images of burial sites were examined for evidence of soil or surface disturbances using a side by side comparison of the following band combinations:
(Bands 4,3,2) False Color Composite (looking for vegetation differences)
(Bands 6,4,2) Short Wave Infrared (SWIR) Composite (looking for soil moisture and vegetation differences)
(Bands 7,6,2) Thermal Composite (looking for thermal anomalies)
(Band 7 or 8) Individual Thermal Bands (looking for warm/cool thermal anomalies).

A Principal Components composite image was created to search for trenches. Each of the first three principal components was given a separate color then the data were combined into a color composite image. Also, a Tasseled Cap Transform, was used to produce estimates of "greenness" and "wetness" (Jackson, 1983 and Tucker, 1979). The Tasseled Cap Transform is an established process for analysis of Landsat Thematic Mapper imagery. The Daedalus scanner bands approximately duplicate the Thematic Mapper. One of the outputs of the Tasseled Cap is a "greenness" transform band which has long been used as an indicator of vegetation vigor and "wetness" which is used as an indicator of vegetative and soil moisture.

A comparison of the daytime and nighttime imagery was conducted to evaluate various areas showing unusual thermal inertia properties and vegetation stress. The comparison can by made by registering night image to daytime image, using side by side analysis, or using change or difference images.

Stereo analysis of aerial photography was performed using the conventional mirror stereo-scope. Some mounds and evidence of subsidence were visible but difficult to assess due to the vegetation cover.

Analysis of Drain Fields: Images of the drain fields were studied for evidence of anomalous vegetation vigor or stress and for soil moisture patterns using the same techniques as for buried trenches.

Fault and Fracture Area Analysis: To analyze fault and fracture areas, the multispectral images were registered to the geologic map, then examined for spectral features within the known fracture region. The remaining area was searched for similar features. A modified Tasseled Cap Transform (Crist and Cicone, 1984) was applied to produce a "greenness" image. The "greenness" image was evaluated to locate areas of vegetation vigor and stress.

Healthy vegetation tends to maintain a relatively uniform temperature (by evapotranspiration). Stressed vegetation often has difficulty regulating its temperature. Ideally, one would like to measure the vegetation's temperature at its minimum and maximum (predawn and mid afternoon). A thermal image of the difference in temperature between these two times a day can provide indications of areas of stressed vegetation. While predawn thermal data was available, the daytime imagery was collected mid-morning. Nevertheless severely stressed vegetation might show a meaningful temperature difference. To do this, the predawn thermal image was geolocated with daytime thermal image, and the predawn image was digitally subtracted from the daytime one. The result was evaluated for vegetated areas with large temperature differences. An overlay was produced digitally merging the results with a geologic map.

RESULTS

The final remote sensing products that were made include the following: delineation of trench and old septic field boundaries using photography, maps and imagery; analysis of thermal signatures in unusual geological strata, asphalt, and buried pits; analysis of fault and fracture areas beneath contaminated areas; comparison of existing engineering drawings of buried objects with imagery; and use of hydrologic data merged with imagery to aid in soil sampling strategies (David and Ginsberg, 1996).

Figures 2-7 show samples of the products that were made. Two of these images, a comparison of suspected trench locations with thermal image features (Figure 2) and an overlay of drain fields on false color composite imagery (Figure 7), are shown in color. All images were produced with the intention of being displayed in color.

Figure 2 is a comparison of suspected trench locations with thermal image features at a contaminated materials disposal area at the Rofer Site. In this area material was buried many years ago. Three side-by-side images are shown: an overlay of suspected trench locations, a predawn thermal image, and an image composite containing both thermal and reflective bands.

The trench overlay image was produced by scanning a trench map developed at Los Alamos (Pope, Van Eeckhout and Rofer, 1995). This trench map was developed by analyzing historical photos taken since 1946. The exact location of trenches where contaminated waste was buried was not known. The trench map was digitally registered to the Daedalus data, pertinent map features were traced into a new digital overlay, and the new overlay was superimposed on a single-band Daedalus image (visible red). The colors indicate the following:

Color	Interpreted Feature (Date of Photo)
Magenta	Suspected Trench (1958-1972)
White	Disturbed Ground (1946)
Red	Circular Anomaly (1946, 1949)
Yellow	Large Mound (1958)
Sienna	Access Road (1946)
Blue	Fence (1991)

The image in the center is a predawn Daedalus thermal infrared image. The arrows point to areas where the apparent temperature is less than that of the surroundings. Many of these "cold spots" coincide with suspected trench or disturbed ground locations. The uppermost and lowermost magenta trenches and the lowermost disturbed ground are particularly good examples. Note also the dark outline corresponding to the long magenta trench in the center of the scene. Part of this may be related to soil disturbance associated with the removal of a fence that was there in 1991. However the dark outline extends up into a clearing (fifth arrow from the top) in which there is no apparent surface explanation for this line. Other "cold spots" occur outside of the annotated area in the upper part of the image and within the annotated area in locations that do not correspond to suspected trenches (in particular, see the rectangular patch along the road in the center of the image).

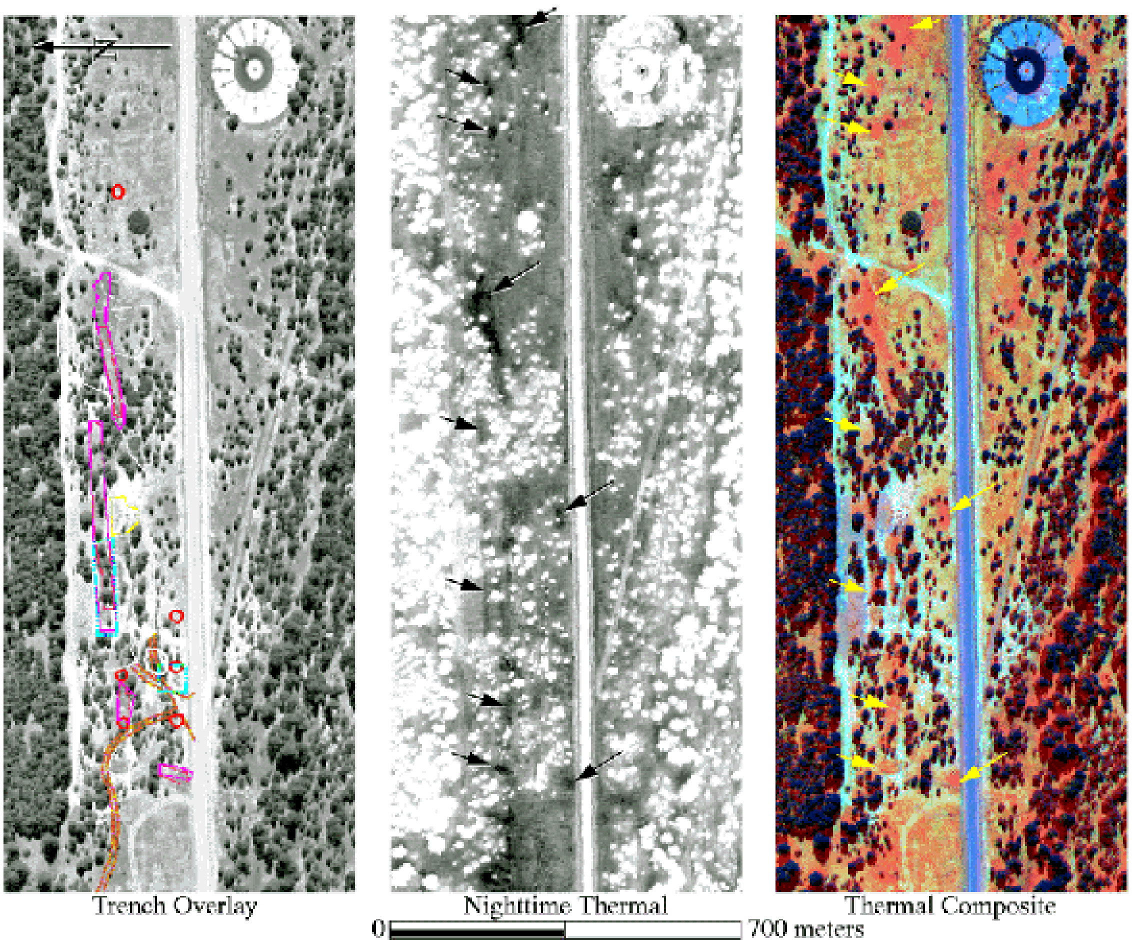


Figure 2: Comparison of Suspected Trench Locations with Thermal Image Features (Rofer Site)

The image on the right is a Daedalus thermal composite of a daytime-nighttime thermal difference image in red, the far SWIR band in green, and the visible-green band in blue. The thermal difference image was formed by digitally merging the predawn data to the daytime data and subtracting the predawn longwave image from the daytime longwave image. The dark areas of the predawn image are correspondingly bright in the daytime image, resulting in bright thermal difference values that accentuate the suspected trenches and similar areas. In the thermal composite, these areas are bright red or reddish orange. The reddish signature is the result of bright thermal difference values in combination with moderately dark SWIR and visible-green values.

A possible reason that these areas are dark in the predawn thermal image and bright in the daytime thermal image is that the soil is less compacted and hence cools down faster at night and heats up faster during the day. Another possibility is that these signatures are associated with a specific type of vegetation, which may or may not be indicative of earlier burial activity. The darker SWIR response may be the result of increased soil moisture in these areas, or it might be related to difference in surface soil composition caused by previous excavation.

Figure 3 is a side-by-side comparison of a nighttime thermal infrared Daedalus image on the left and a natural color composite of an asphalt closure cap at the Mason Site on the right. The area was capped to cover a buried contaminated materials area. The thermal image shows warm thermal anomalies as dark areas. The upper arrows point to anomalies which can be explained as resulting from patching material. The other arrows point to two large anomalies and a few small anomalies which cannot be explained by changes of surface properties. The patches are visible in the natural color composite and the thermal image but there is nothing visible in the color image to explain the anomalies. They are suspected to be areas where water has leaked through cracks in the asphalt cap. Site managers are concerned about the potential implications of these anomalies, that the water may be contaminated or that some other chemical activity is present below the surface.

Figure 3: Nighttime Thermal and Daytime Image of Asphalt Closure Cap (Mason Site)

Figure 4 is a side-by-side comparison of a natural color composite (left) and nighttime thermal image (right) of an old laundry area for contaminated uniforms and an adjacent uncapped trench area with experimental monitoring sites. This is also located at the Mason Site, near the asphalt cap area, appearing at the bottom of the image. The former laundry area was dismantled and is now being used as a parking lot. The nighttime thermal image shows the thermal shadows (dark spots) left behind by departed vehicles. These shadows make it difficult to assess this area because they overwhelm the other features at the site. However, there is an unexplained rectangular cold spot at the far end of the area that could be a shallow buried object or pit.

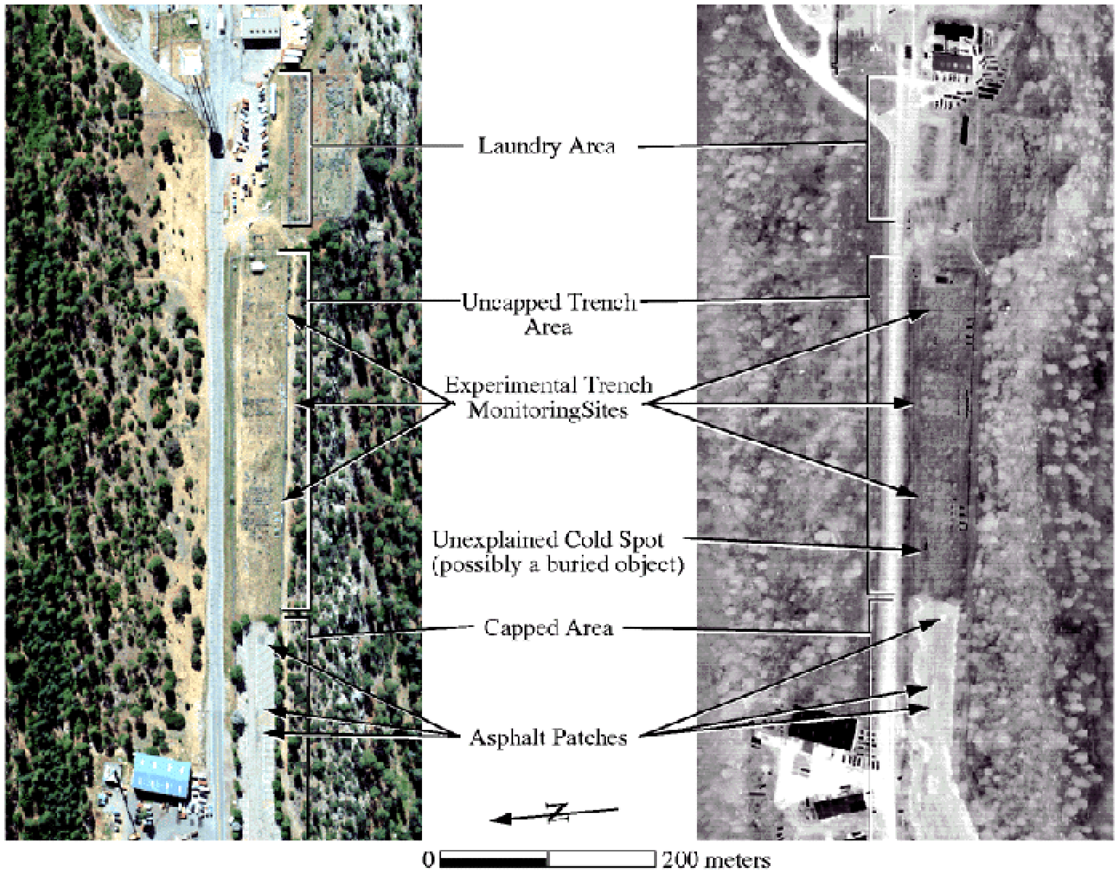


Figure 4: Natural Color Composite and Nighttime Thermal Image of Laundry Area and Adjacent Burial Areas (Mason Site)

The upper portion of Figure 5 contains a "cut-out" of a canyon watershed from the SPOT image on Figure 1. The middle portion of the figure contains graphics representing sampling strata. The bargraphs at the bottom indicate the means and standard deviations of concentrations of the contaminants copper, lead, and uranium (in ppm) that were detected in soil samples in each strata (Becker, David, and Hoopes, 1995). This kind of map is used to guide stratified soil sampling procedures. Strata have evolved based on hydrological features of the watershed and other information. Where standard deviations are quite different stratum-by-stratum, as in this case, stratified procedures require fewer samples for the same accuracy as random or grid sampling procedures.

Figure 6 shows a 1962 engineering drawing of materials disposal trenches at the Hoard Site, overlaid on a 1994 aerial photograph and a historical photograph from 1958. Surface scars in the 1994 photograph extend well beyond the areas drawn for the larger trenches but the smaller trenches are not seen. In the old photograph, one of the trenches is open and is clearly larger than indicated in the engineering drawing.

Engineering drawings of material disposal areas are often incorrect; however, site managers must reconcile them before remediation can start. Remotely sensed data can help identify errors and supply evidence to help determine more precise location of burial trenches. The photographs indicate that even the concrete pad was incorrectly mapped. Careful inspection of the trenches (dashed lines) along the short sides of the enclosure (line with circles) suggests that some trenches may be considerably longer than mapped. The L-shaped trench in the engineering drawing, in the interior of the closure, is not seen in either image and is not referenced in any other current site information.

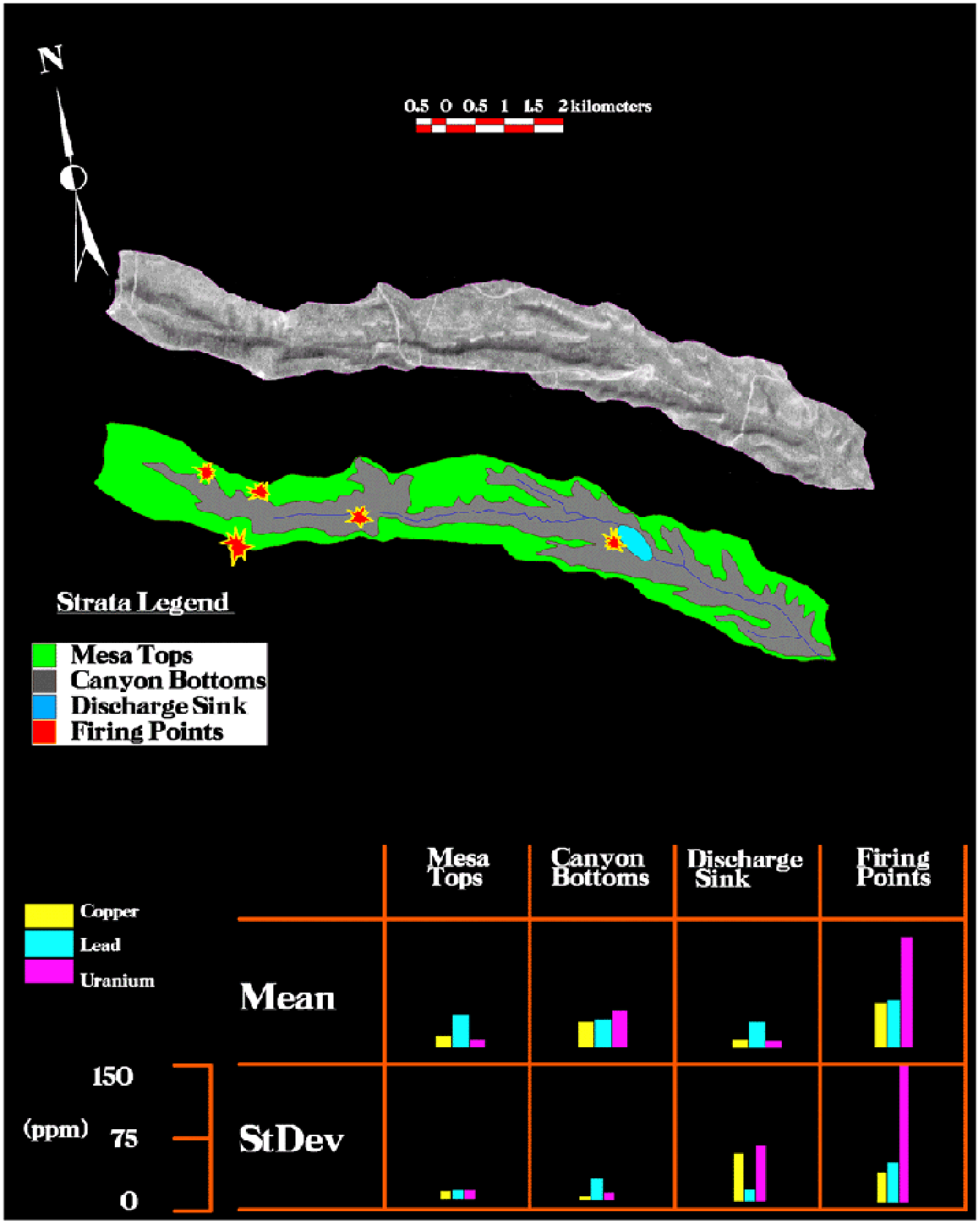
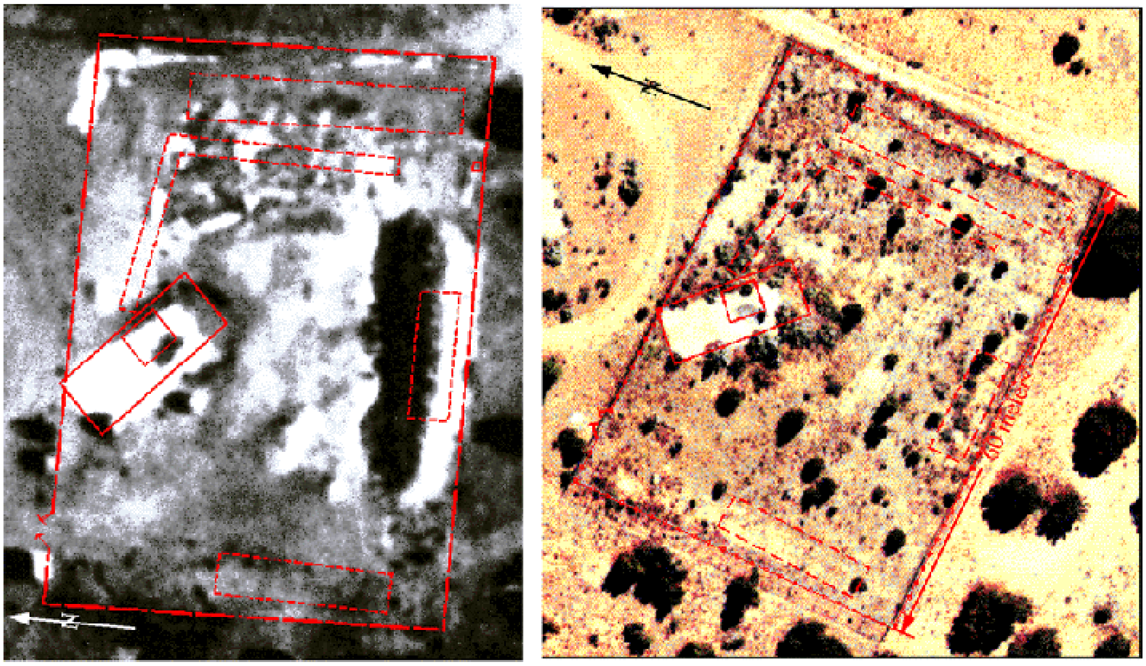


Figure 5: Means and Standard Deviations of Contaminants in ppm for Four Strata (Becker Site)



November, 1958 June, 1994

Figure 6: Engineering Drawings of Fencelines from 1962 Overlaid on Historical and Current Aerial Photographs of Materials Waste Pit (Hoard Site)

Figure 7 is an overlay of engineering drawings that are presumed to indicate the boundaries of old contaminated drain fields at the Mynard Site. The site manager was interested in the accuracy of these drawings and was looking for possible seepage. The engineering drawings are overlaid on a Daedalus false color composite image containing the near-infrared band in red, the visible-red band in green, and the visible-green band in blue. The line drawings were scanned, and merged with Daedalus data.

There are red areas beneath the drain field overlays (indicated by black on white arrows). In this composite, red results from high reflectance in the near infrared and low reflectance in the visible red, which in turn generally indicates healthy vegetation. These red areas may be linked to better drainage or more abundant nutrients due to the presence of the drain fields. Note also the heavy vegetation near the bend in the drain tile just before it passes under the bridge. Leaks commonly occur at junctions like this and this vegetation may be benefiting from some seepage. On the right image, there is a red linear feature just to the right of the drain tile leading away from the drain field. This may indicate that the drain field is misplaced on the map.

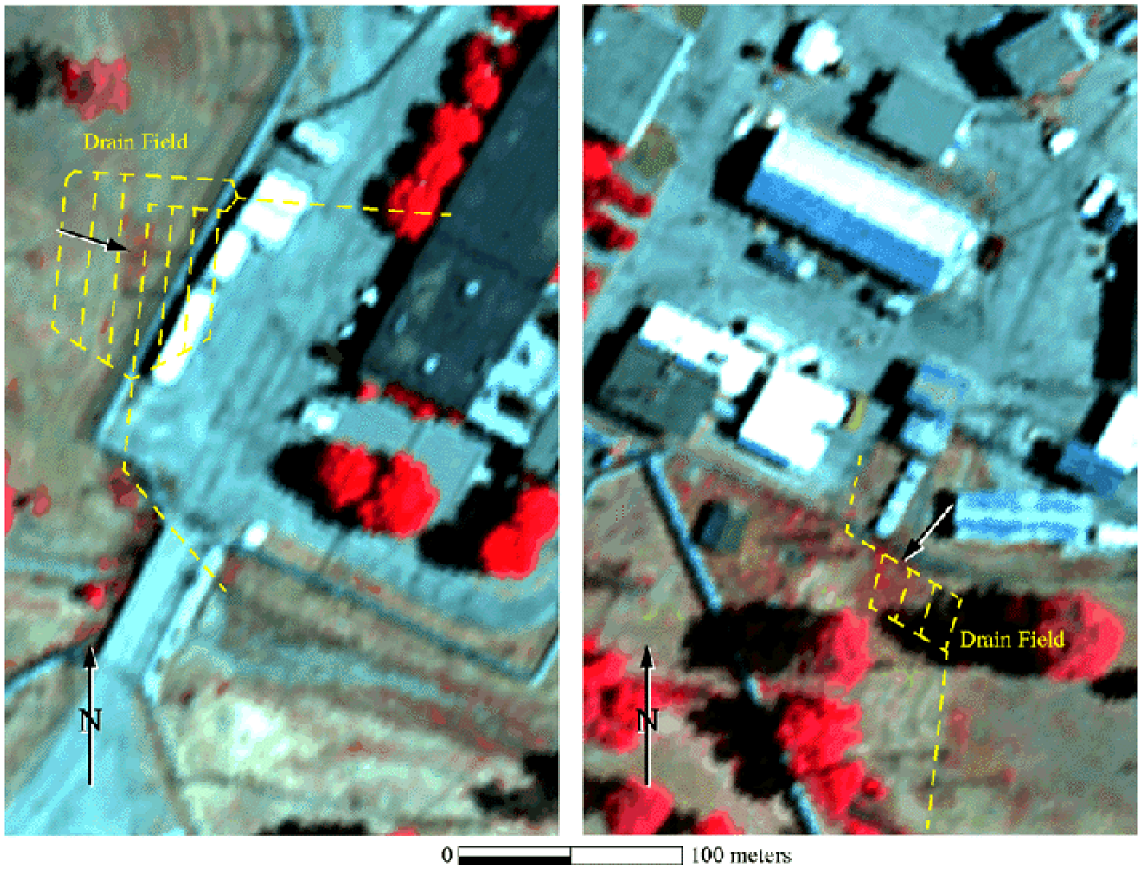


Figure 7: Overlay of Drain Fields on False Color Composites of Kivas/Central Area (Mynard Site)

APPLICATIONS

Economy: Rather than (or in conjunction with) statistical methods, analysis of remotely sensed data will provide information on where waste is located and on where wells should be drilled in order to obtain definitive characterization of waste sites. This would reduce the expense of exploratory drilling and the necessity for fine-gridded sampling.

Accuracy: Remote sensing's capability to provide (relatively) continuous information can be used to extrapolate conditions between wells/boreholes. This would improve the accuracy of information derived from point-sampling, and also would provide better data for waste-flow models.

Safety: In many situations, there are risks associated with inadvertently drilling into containers and in working in areas where hazardous waste has migrated to the surface. Such conditions may not be known beforehand. Remote sensing provides the capability to detect and map such hazardous areas prior to beginning clean-up and mitigation.

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